AT A GLANCE

Overview

Using a stream table and setting it at various inclinations, students develop an eye for features associated with flowing water. To consider the idea of whether water once flowed on the surface of Mars, students choose three Martian landforms that seem to have been shaped or created by flowing surface water and discuss how they may have formed both with and without flowing water. Also, by examining how flowing water sorts particles according to size, students see what sediment can reveal about the speed of the water that deposited it. Finally, students examine images of Mars to see if there are any features suggesting the presence of flowing water at one time or another.

Content Goals

- Flowing water creates characteristic features that can be used to interpret water flow.
- Most river and stream beds have inclinations below 5 degrees.
- Small, light sediments are carried more easily by flowing water than large, heavy ones.
- Gently-flowing water sorts sediments in predictable, consistent ways.
- Models such as stream tables can represent real-world processes.
- Various Martian landforms seem to support the idea that water flowed across the surface.

Skill Goals

- *Observing* and *recording* the features created by the flowing water.
- *Hypothesizing* about the effects of using different angles, amounts of water, and rates of release, and then *testing* these ideas through experimentation.

Possible Misconceptions

- River beds are commonly quite steep, certainly above 10 degrees.
  Ask: How steep is a typical river bed?
- Water alters the land only minimally.
  Ask: In what ways does water affect the land?

Materials

Calibrated stream tray (a lightweight plastic tray about a meter long and 10 cm wide which costs about $1 in a paint store), sand, water jug, stand (or pile of blocks), protractor, dice or similar 1 cm cubes, small (i.e., nine-ounce) paper cups, large (i.e. 24-ounce) cups

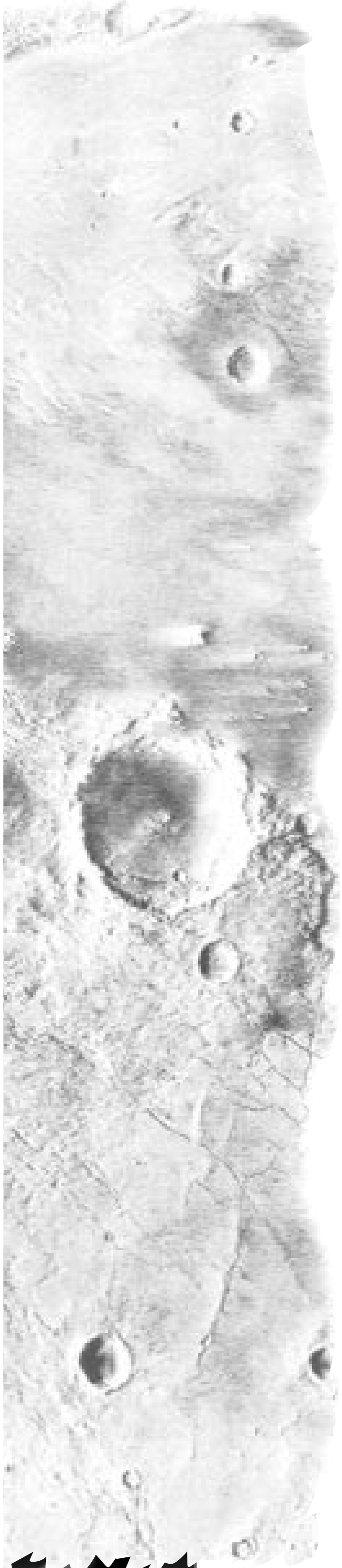
Preparation

- Mark cm lines along both sides of a wallpaper tray. Be sure both sides have zero at the same end of the tray.
- Read Mike Caplinger's essay, "Channels and Valleys," at the end of this activity.

Time

2-3 class periods

BACKGROUND



One tool geologists use to learn about the effects of flowing water is a stream table. In this activity students use a simplified version of a stream table to study stream bed steepness and to identify telltale clues of flowing water such as mud flows, meanders, streamlined landforms, braided channels, outwash plains, alluvial fans and islands. Also, by examining how flowing water sorts particles according to size and density, students see what sediment can reveal about the speed of the water that deposited it. Finally, students look at images of the surface of Mars to determine whether water actually flowed across the surface.

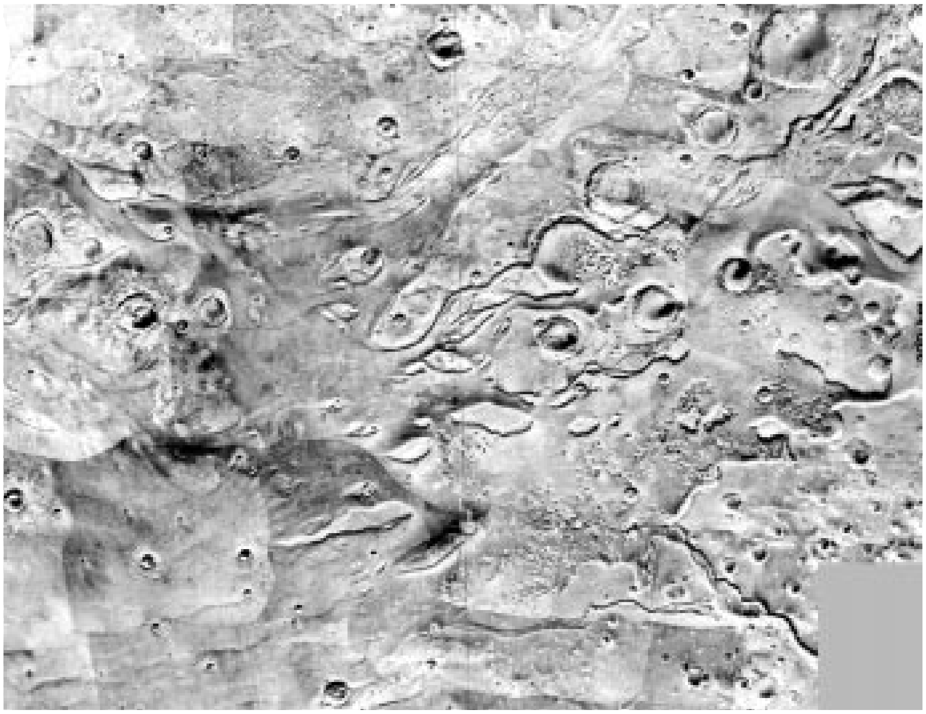


Image of where the Ares and Tiu Valleys join the Chryse Planitia.
Image Set Image #5.

PROCEDURE

Part A: How Does Flowing Water Shape A Surface?

1. Line the tray with a layer of damp sand about 2 cm deep.

Fig. 1.1
Cross-sectional view of the channel in the sand.

2. Design a standard river bed containing a small bend. Sketch the starting layout.
   To make a standard starting river bed, depress a centimeter cube in the sand to make a centimeter-deep channel (see Fig. 1.1 & Teaching Pointers).

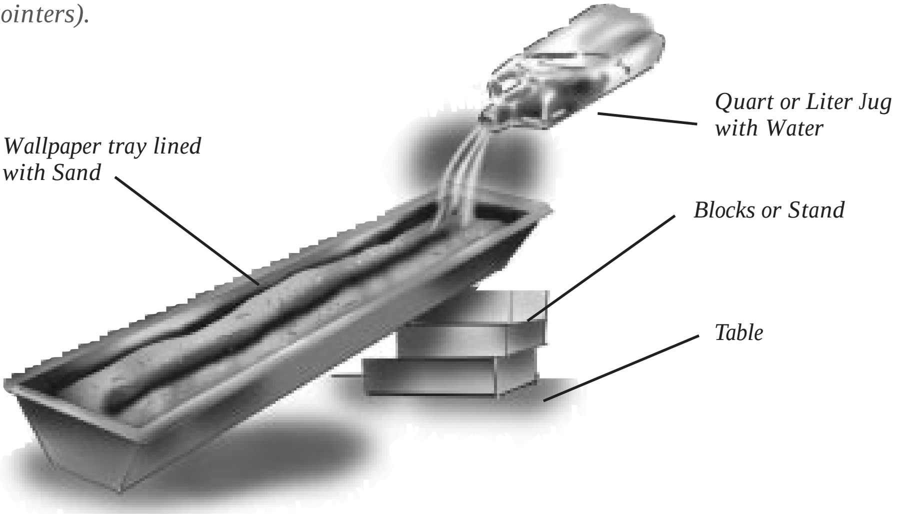


Fig. 1.2
Activity Setup.

3. Set one end of the tray on your stand (or pile of blocks) and adjust the stream table so it sits at an angle of 20 degrees (Fig. 1.2). *(Avoid using books which accidentally might get wet.)*

4. Release just enough water so there is a steady stream flowing in the channel.
   Use a quart or liter bottle. Fill it only a quarter full and have students refill each time. If it is filled too much, the water will pour out unevenly. To assure an even, gentle flow, pouring from near the lip of the tray is recommended.

5. Have students watch what happens to the bend. Does it move? If so, how far? Does the flowing water move it upstream or downstream?
   In Step 8 students will change the slope of the tray. The water will create mud flows and destroy the bend until the tray angle is close to 5 degrees. However, destroying the bend is precisely the point. For students to understand that the inclination of river and channel beds is, in fact, quite low – below 5 degrees, creating the mindset that "everything turns into a mud flow" is desirable. By having students expect only mud flows, they are genuinely surprised when, near 5 degrees, they observe flowing water behave in quite a new way.

6. After releasing all the water or as soon as the bend is destroyed, describe or draw what happened to the bend. Note any shapes created, the extent of the erosion, mud flows, wash-outs, etc. Use the calibrations on the sides of the stream table to document where each feature occurred. Note if the flowing water had an effect right away or only after it had flowed for a while.
   Feign surprise at all the mud flows. Don't let on that you know that there will be nothing but mud flows until the tray angle is near five degrees.

7. Using the large and small cups, scoop the water out of the end of the tray, smooth the sand, and restore the river bed to the standard starting river bed.
   Large cups enable students to remove most of the water, but they will need smaller cups to eliminate all the standing water. All waste water should be put into collecting buckets which get dumped outside or in a toilet. IF SAND-LADEN WATER IS PUT INTO A SINK, IT WILL CLOG THE SINK.

8. Repeat Steps 1-7 three times using 15, 10 and 5 degrees as the new stream table angles.
   You may want to shorten the activity by using 25, 15 and 5 degrees as the tray angles. However, the benefit of doing trials at 20, 15, 10 and 5 degrees is that students get a lot of experience with mud flows and observe with particular care as the braided channels, meanders and islands form at the low angles.

9. In a table summarize what happened as the stream table angle went from 20 to 15 degrees. From 15 to 10 degrees. From 10 to 5 degrees. From 20 to 5 degrees. Also, write a statement that summarizes the relationship between the rate at which the water flows and its ability to erode the sand.
   This data is qualitative and does not lend itself to easy categorization. Nonetheless, students can succeed in this activity using qualitative data. See if your students can devise ways to quantify or systematize this information. Creating such tables is a valuable exercise in classifying and organizing data. Can this data be graphed? What kinds of graphs can and cannot be used?

10. Report your data.
    You may want to have groups report their data to a class data table. For the higher tray angles, you probably will end up writing "mud flow." It is important for students to realize that river and channel beds are actually quite shallow.

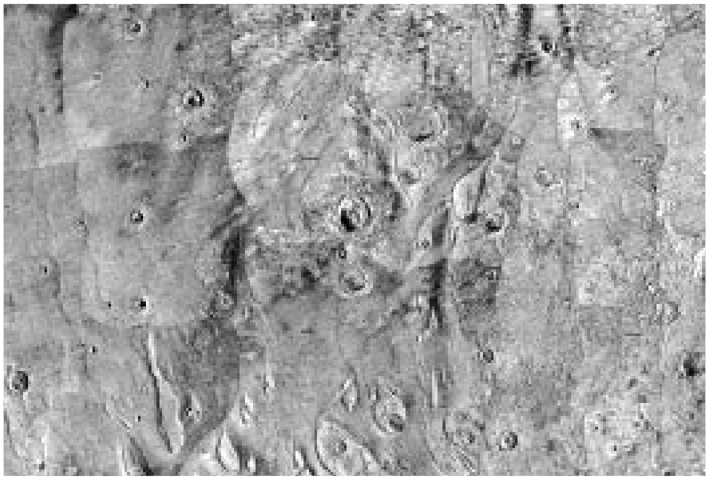


Image #4 from the Image Set showing where the Ares Vallis joins the Chryse Planitia.

Part B Observing How Flowing Water Sorts Sediments

11. Create the standard river channel (Fig. 1.1) and incline the stream table at 3-5 degrees.

12. Start a continuous flow in the channel. Watch the motion of individual sand grains along the stream banks and identify patterns in how flowing water carries sediments.

   - Does flowing water pluck sand grains from the upstream or downstream side of the bend?
   - Where do those grains get deposited?
   - Add pebbles to the sand to look at the way obstructions effect erosion.
   - Compare the effects of flowing water on large and small-sized sediments.

Small, light sediments are carried more easily by flowing water than large, heavy sediments. Fast flowing water has more energy and can carry larger sediments (i.e., pebbles and rocks) than slowly flowing water. Consequently, along a waterway one expects to see well sorted sediments with small, light sediments downstream, at the bottom of areas of calm flow such as pools, and on the inside of meanders. It is important for students to understand this as the typical arrangement because it raises an important question when they encounter sediments that show no such pattern.
In Activity 4, students will encounter gravel and 120 ton boulders in the same deposit, suggesting deposition by floods.

13. To experiment further with how flowing water carries sediments, float a small, colored candy or small piece of paper down the flowing water.

14. Summarize how gently-flowing water typically sorts sediments.

Questions

1. Why was it important for the class to agree on the shape of the standard starting river bed, the amount of water to use and how to release the water?

2. How would you make the water flow if you wanted to:

   a) move a lot of sediment from the headwaters to the mouth of a stream?

   b) create features such as islands, sand bars, pools and braided channels?

   c) cut a deep stream channel?

   d) create a delta where a stream enters a lake or ocean?

   e) create a winding stream?

3. Using maps or direct observation, can you identify any examples of shapes you saw in the stream table in the rivers and streams that flow in your local area?
Find maps of waterways in your area that have islands, sandbars and deltas. USGS topographic maps show such features in detail.

APPLYING THE MODEL TO MARS

The stream table shows that water makes distinct patterns when it erodes a landscape and deposits sediments. For water to have flowed on the surface of Mars, the planet would have to have been a very different place -- far warmer and with a denser atmosphere. Can planets change so drastically? Could Earth ever become a cold, dry planet like Mars? Such questions are among the mysteries posed by Mars. In this part of the activity, students are asked to find evidence that either supports or sows doubt about the claim that liquid water flowed over the surface of Mars.

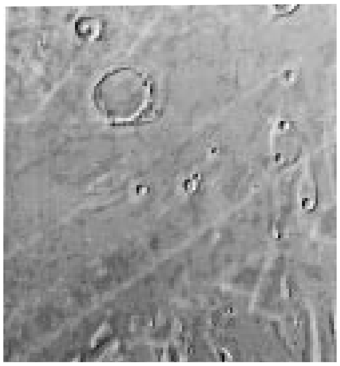


Fig. 1.3
The Chryse Planitia at the Mouth of Ares Vallis. Image Set image #3.

Ask the students to do the following:

1. Compare the shapes they observed in the stream table with Martian land forms in the image packet. Identify as many ways as possible that these landforms and stream table shapes are alike and different.
2. Choose three landforms that seem to have been created or shaped by flowing surface water.
3. For each of these landforms, create two lists. In one list, include ideas supporting the concept that flowing water shaped each landform. In the other list, provide alternate explanations for how each landform could have formed in the absence of water.
4. Use the library (or Web) to research the question: Why do people think present-day Mars cannot have substantial amounts of liquid water at the surface?

Mike Caplinger has written a superb essay, "Channels and Valleys," discussing some of the evidence for water having flowed on Mars. It appears at the end of this activity. Read it before doing this part of the activity because in it he lays out much of the evidence for water flowing on Mars, and he provides many images to support this idea.

In this and subsequent activities, the use of the word SAND may lead students to expect to find sand on Mars. Surprisingly, no sand has been found on Mars. Several explanations have been put forward:

- *The tremendous winds seem to have pulverized the "soil" into a fine silt texture;*
- *The rocks on Mars may be fine-grained and do not weather into sand-sized particles;*
- *Weathering, and not the wind, has reduced surface particles to silt and dust size.*
- *Sand may be abundant, but there did not happen to be any at the two landing sites of the Viking mission Students could be encouraged to express their ideas on why the Viking landers did not find any sand-sized particles. They could compare the surface area of Mars to the land area of Earth (they are nearly the same) and ask themselves: If two landers came to Earth, what are the chances that they would find sand within a few feet of their landing sites?*

TEACHING POINTERS

Since you want to be able to compare results from different groups, it is important to use standard procedures. For example, for the standard river, have students think about: how deep the channel should be, where it should bend, how far the channel should bend away from the mid-line, how long the run of the bend should be, how much water to use, and how the water should be released. Though students can obtain similar results with a straight channel, the bend gives them something specific on which to focus and collect data. One very successful setup is making a straight channel to the 25-centimeter mark on the tray, smoothly swing it one centimeter away from the tray's mid-line, and then have it rejoin the tray's mid-line at 30 centimeters (Fig. 1.4).

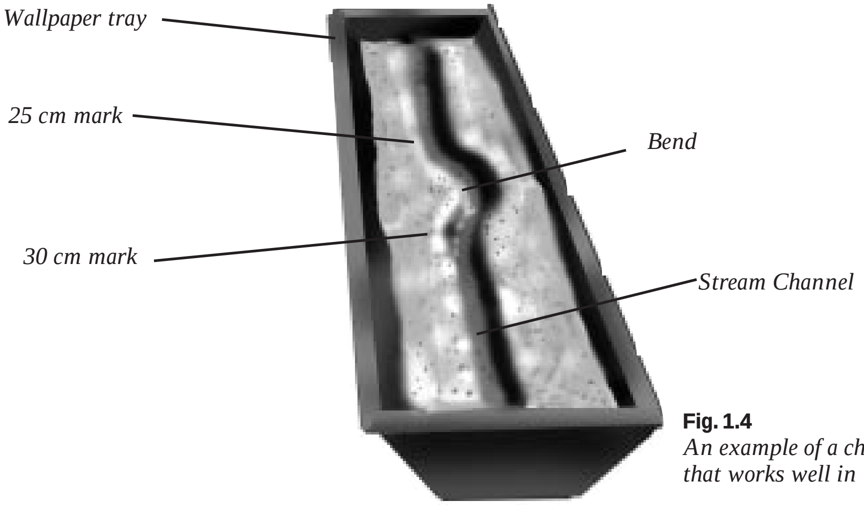


Fig. 1.4
An example of a channel design that works well in this activity.

For the best flow rate, release just enough water so a steady stream flows in the channel. For the effects to show, the stream need only flow thirty seconds to a minute. Another way to control the flow is to pour the water into a funnel held over the upper end of the stream table. Its release rate is partly predetermined by the diameter of the funnel's opening.

EXTENSIONS

After establishing that stream features form only at low angles and identifying patterns in sediment sorting, have students collect data on:

- which side of the bend sediments are deposited and removed.
- what landforms are created at angles lower than 5 degrees.
- at what angles do braided channels and streamlined islands form.
- what happens when water is released at different heights or rates or in different amounts.

Channels and Valleys

by Mike Caplinger
Malin Space Science Systems (mc@msss.com)
from the Mars Educational Multimedia CD-ROM
produced by the Center for Mars Exploration
(415) 604-0421 or cmex_cd@barsoom.arc.nasa.gov

Under current conditions, liquid water on the surface of Mars would either freeze or evaporate almost immediately. The atmosphere, too, is almost without water. Thus, one would not expect to find features that look like those carved by rivers and floods on Earth. But, surprisingly, these can be found almost everywhere on the planet. How and when were they formed?

These features are divided into two types: outflow channels and valley networks. Outflow channels originate in areas of chaotic terrain which are considered the source for immense amounts of floodwater that etched these channels into the Martian surface. Valley networks are present over almost half the planet and, superficially, are reminiscent of the branching river patterns observed in terrestrial river systems. The outflow channels occur mainly in the young surfaces in the northern lowlands (from the Amazonian period of Martian history), while the valley networks occur throughout the older heavily-cratered terrains of the Noachian and Hesperian periods. This suggests that the outflow channels were formed after the valley networks.

(As an aside, it must be noted that "young" is a relative term. Since the main techniques we have to date surfaces on Mars are based on the cratering record, it is difficult to resolve ages after the period of heavy bombardment that created most of the craters, and this period ended perhaps as long as 3.8 billion years ago. So even though the outflow channels are younger than the valley networks, they are probably not young in any absolute sense.)

Fig. 1
Map showing the location of most of the outflow channels. Image Set image #16.

Outflow Channels

Most of the outflow channels are in the northern lowlands north of Valles Marineris, just west of the Chryse region (Fig. 1). The outflow channels are large, often more than 100 km wide and as much as 2000 km long. They emanate from cracked or jumbled terrain (termed chaotic terrain) and have distinct flow features such as eroded craters with teardrop-shaped tails, scour marks, and "islands".

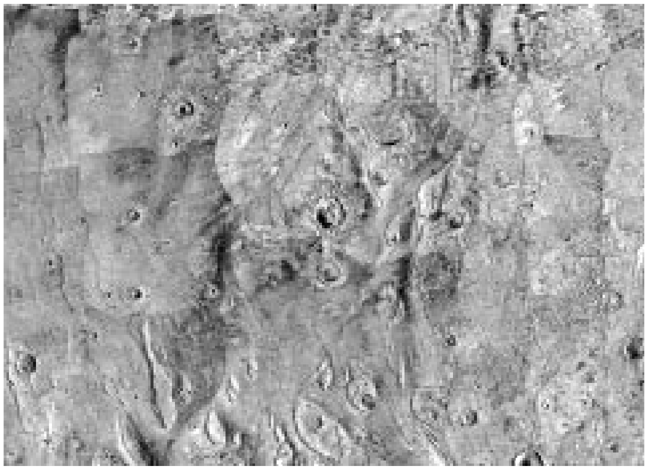


Fig. 2
Tiu Vallis. Image Set image #4.

Tiu Vallis (Fig. 2) appears to have started from an area of collapsed terrain, a region known as Hydaspis Chaos (Fig. 3), moved northward through a fairly narrow channel, and then spread out and eroded a large area to the north and west. A more detailed view of the source shows the chaotic terrain, the initial channels, and various eroded features.

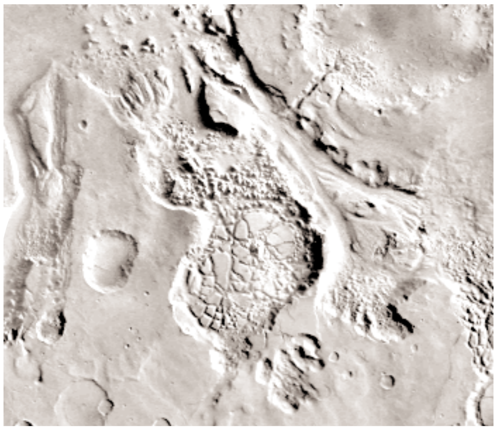


Fig. 3
Hydaspis Chaos, the source of Tiu Vallis.

Erosional features in the outflow channels often form around obstacles such as craters, such as these at the mouth of Ares Vallis (Fig. 4). As generally interpreted, the streamlined islands were protected from the fluid flow's erosion by the craters. (An alternative hypothesis is that the tails are depositional features where material was laid down in the lee of the crater during the flow.)

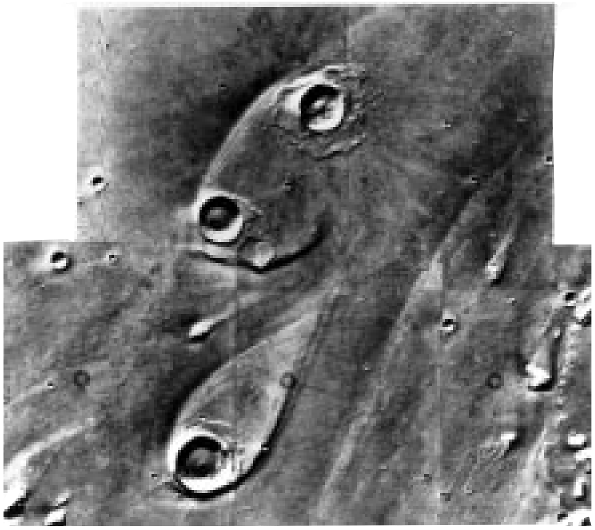


Fig. 4
Eroded Craters at the terminus of the Ares Vallis. Image Set image #10.

Not all of the outflow channels start in chaotic terrain; some, such as Mangala Vallis, appear to start at deep cracks known as grabens (Fig. 5).

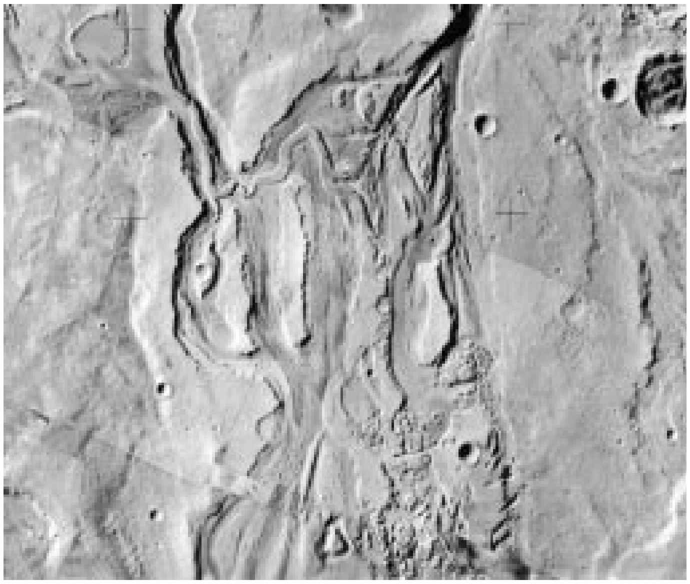


Fig. 5
Source of Mangala Vallis.

What formed the outflow channels? The most commonly-accepted view is that they were formed by catastrophic floods of water released from large groundwater reservoirs. The water would have flowed across the terrain, simultaneously freezing and evaporating. Some speculate that the chunks of ice that would have rapidly formed enhanced the erosive power of the flood. The flow might have frozen over at the surface, continuing to flow underneath, much as a frozen river might.

There are some objections to the catastrophic flood explanation. There are no obvious deposits at the ends of the channels; all the material that was eroded away by the flood would have presumably been left there, but it is not seen in the orbital photos. In addition, the volumes of the source areas don't seem to be large enough to account for all the water that would have been required to erode the affected areas, based on models of the efficiency of erosion by water.

Fig. 6
Artist's conception of a catastrophic flood sweeping down the Columbia River.

Catastrophic floods have occurred on Earth. For example, the Channeled Scabland of Washington State was formed by the breakout of water from the Pleistocene Lake Missoula (Fig. 6), and this area resembles the Martian outflow channels in many respects. However, it is much easier to understand how standing water could accumulate in a lake and then break out of the lake's boundaries than it is to see how large amounts of groundwater could suddenly be released. Since lakes on Mars are impossible under current atmospheric conditions, the groundwater hypothesis has the advantage of being possible under current conditions, without requiring a period of denser atmosphere and a wetter climate in early Martian history.

As with many other aspects of Martian geology, we really won't be sure exactly how the outflow channels formed until we can do fieldwork on the planet. It may be possible to get a better idea using higher-resolution imaging data taken from orbit, and this is one of the things we hope to examine using the *Mars Observer* camera. The images taken at the surface by *Mars Pathfinder*, which will land in the outflow region of Ares and Tiu Valleys, will also shed light on this issue.

Valleys Networks

The valleys can be loosely divided into two subtypes: long, winding valleys with few tributaries (Fig. 7), and smaller valley networks, often with complex, multiply-branched patterns of tributaries (Fig. 8).

Fig. 7
Nirgil Vallis, an example of a long, winding valley network south of the eastern end of Valles Marineris.

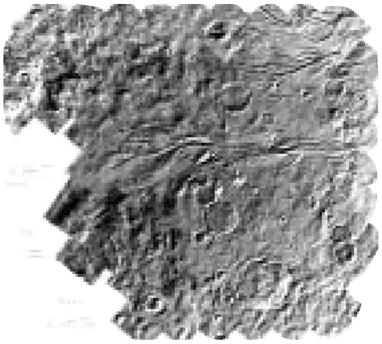


Fig. 8
A small, winding valley network in the Lunae Planum.

Superficially, the valley networks resemble river-cut valleys on Earth, and initial speculation focused on this explanation for them. Despite the fact that there is no running water or rain on Mars at the present time, earlier in Martian history such conditions might have prevailed. However, on further examination, there are significant differences between the Martian valleys and river valleys on Earth. First and most important, a terrestrial river valley contains a river, or at least a dry river bed, and no such features have been seen on Mars at the resolution limit of our current images. (It is important to note that a valley is not a channel -- the fluid never filled the valley up to its rim, but was carried only in the channel that cut the valley over time.) In addition, even the densest tributary networks on Mars are much sparser than their terrestrial counterparts. These facts argue against a purely running-water origin for the Martian valleys.

An alternate explanation involves sapping processes, the weathering and erosion of terrain by emerging groundwater. When the underlying soil is weakened by groundwater flow, the overlying surface collapses. Similar processes have acted on Earth in, for example, the Navajo Sandstone of the Colorado Plateau. This explanation works well for the long winding valleys such as Nirgal Vallis. For the more complex small valley networks, a mixture of the two mechanisms may be required, in which the valleys were initially formed by runoff of water, and then enhanced by sapping.

Conclusions

Today, based on our observations from orbit, Mars appears to be very dry. There is little water in the atmosphere and only a small amount of water ice in evidence on the surface. Yet the planet is covered with features that are best explained by the movement of water, either in catastrophic floods or the slow movement of groundwater. Whether that water was present early in the history of Mars and was lost to space over eons, or is still present in great underground deposits of ice and groundwater, is a question whose answer must be left for the future exploration of Mars.

AT A GLANCE

Overview

Students study images of Martian teardrop-shaped landforms and list what they think are the most important reasons for why these landforms took on their particular shapes. They identify the variables and attempt to recreate the teardrop shapes in the stream table. By attempting to create a specific shape in their stream table, students gain experience in experimental design and in how altering variables leads to different results.

Content Goal

The teardrop-shaped landforms at the mouth of Ares Vallis lend strong support to the idea that water flowed on Mars.

Skill Goals

- *Designing* and *conducting* experiments to test hypotheses.
- *Controlling* variables to understand cause and effect.
- *Documenting* the experimentation carefully so that others can repeat the work.
- *Analyzing* the data collected in a data table.

Possible Misconception

Landforms are shaped the way they are for no particular reason.

Ask: How do mountains, valleys, plains, etc. get their shapes?

Materials

Stream table, different grades of sand, cake frosting, bottle caps, assorted materials related to the set ups you create, image packet and as many additional images of the teardrop-shaped landforms at the mouth of Ares Vallis as possible.

Time

1-3 class periods

In Activity 1, students released the water and observed its effect on the sand. Activity 2 has a different goal. Rather than leaving the shapes up to chance, students are asked to create a very specific shape – landforms similar in shape to those at the mouth of Ares Vallis pictured in Fig. 2.1.

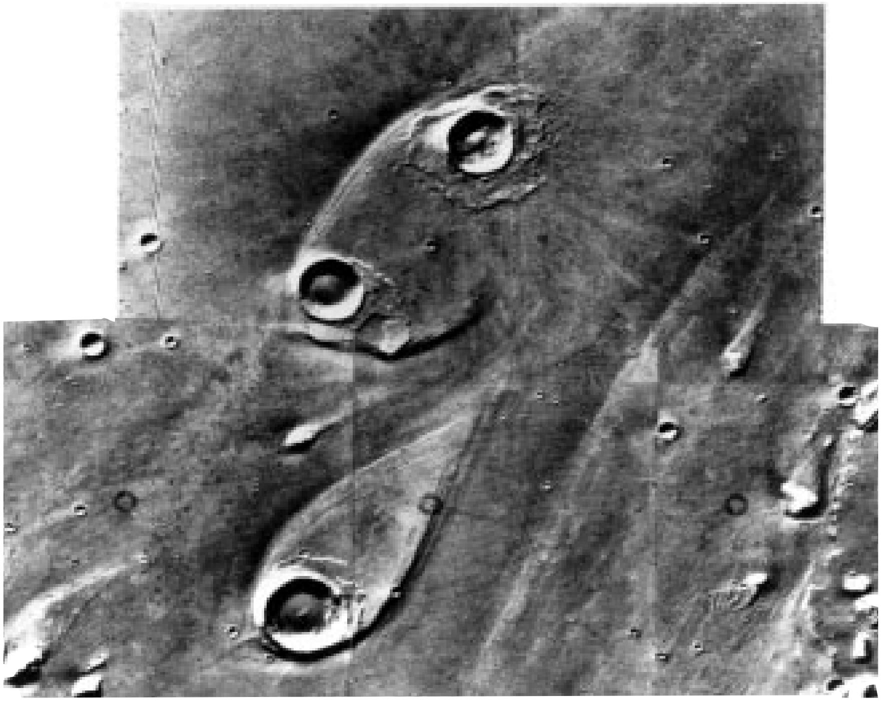


Fig. 2.1
Landforms at the Mouth of the Ares Vallis. Bottom landform is 45 km in length.

PROCEDURE

1. Have your students study Image 10 and list the three things they think were most important in having these landforms take on their particular shapes.
   This might include things such as the crater, the direction of water flow, the rate of water flow, the size of the sediments, the height and initial shape of the landform, the degree of soil compaction, the relative positions of the three craters, etc.

2. Have students make a list of all the things they could change (i.e., the variables) in order to create particular shapes in the stream table.
   This might include the stream table angle, size of particles making up the channel bed, the amount of water used, the length of time the water flows, the rate of release, obstacles in the water course, the amount of sand in the stream table, the compaction of the channel bed, etc.

3. As a class, discuss the topics below.
   - What is the actual size of the crater and landforms?
     (Landforms are 45 km [28 mi] long. Crater is 10 km [6.25 mi] across.)
   - If the channel in the stream table were scaled up to the width of Ares Vallis (25 km [16 mi]), how big would the scaled-up sand particles be? What is the significance of this?
     (The sand particles would be boulder size at a comparable scale and therefore the surface textures of the channel and the model will be different.)
   - Did the impact craters come before the shaping of the landform? *(Yes)* How can one tell?
     (Its ejecta blanket has been eroded.)
   - Have students look at Images 1 or 5. What does the presence of many streamlined landforms over a wide area suggest? *(Large amounts of water may have flowed at one time.)*

4. Review the activity challenge and ground rules below with your class.

5. Once a group has obtained a teardrop-shaped landform and the class has seen it, ask them to repeat their initial success by following the procedure they wrote down.

Challenge

Create landforms in the stream table similar in shape to those pictured in Image 10.

Ground Rules

a) Flowing water can be the only shaping agent.

b) Prior to releasing the water, you can prepare the channel in any way except by actually forming the landform shapes you are trying to have the water create.

c) For each setup you must document how you prepared the channel, which variables you held constant and which ones you changed, and how the water affected the setup. The documentation has to be specific enough so that some one else could achieve a similar result by following your descriptions.
Students might consider varying things such as the inclination of the stream table, rate of water flow, amount of water, presence of obstacles, degree to which the sand is packed, or size of sand grains (if different grades are available). They might also see if having impact craters makes a difference.

TEACHING POINTERS

You may want to let students experiment with different materials for the stream channel. For example, finer sand will give different results than large-grained or mixed sands. Some teachers report obtaining shapes nearly identical to Image 10 using prepared cake frosting. This is not as surprising as it may seem. Scale is a problem in the stream table. When comparing the sizes of the channels in the stream table and Ares Vallis, each sand grain in the stream table is more on the scale of a gigantic boulder. The stream table channel and sand would have to be much smaller to properly represent the channel and silt in Ares Vallis. We cannot make the channel much smaller, but we can make the particles comprising the channel smaller. Hence, cake frosting. Cake frosting's particle size is smaller than sand’s, and it is malleable and can be shaped by flowing water.

Set out a variety of items such as bottle caps, pipe cleaners, straws, nuts, bolts or pebbles and sticks to direct the flow of water and blocks to tamp the sand. Let students select from the assortment. They should think carefully about the role of the craters and use materials and techniques to reproduce their effects. It is likely that students will notice teardrop-shaped islands forming around craters. Bottle caps set in the frosting with the stream table set at about a one-degree slope work well.

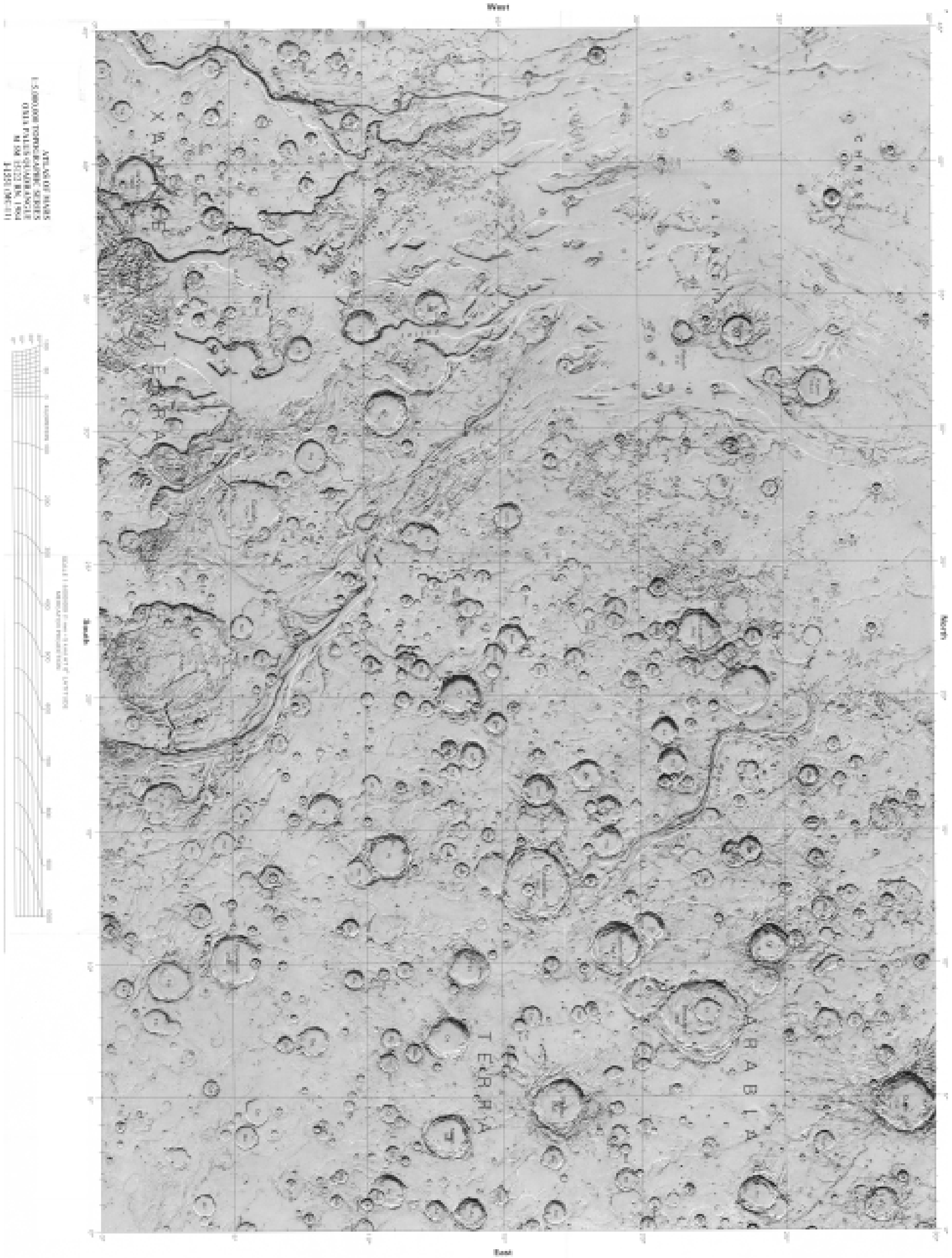


Image 1 Regional map of the channels descending from the highland plateau to the low-lying Chryse Planitia (*Chryse plain*) 2-3 km (1.25-2 mi) below. This map adjoins Image 2.

Image 3 **Photomosaic *(i.e., using many small images to create one large image)* of the terminus of Ares Vallis where it joins the Chryse Planitia, and a close-up of the *Pathfinder* landing site.**

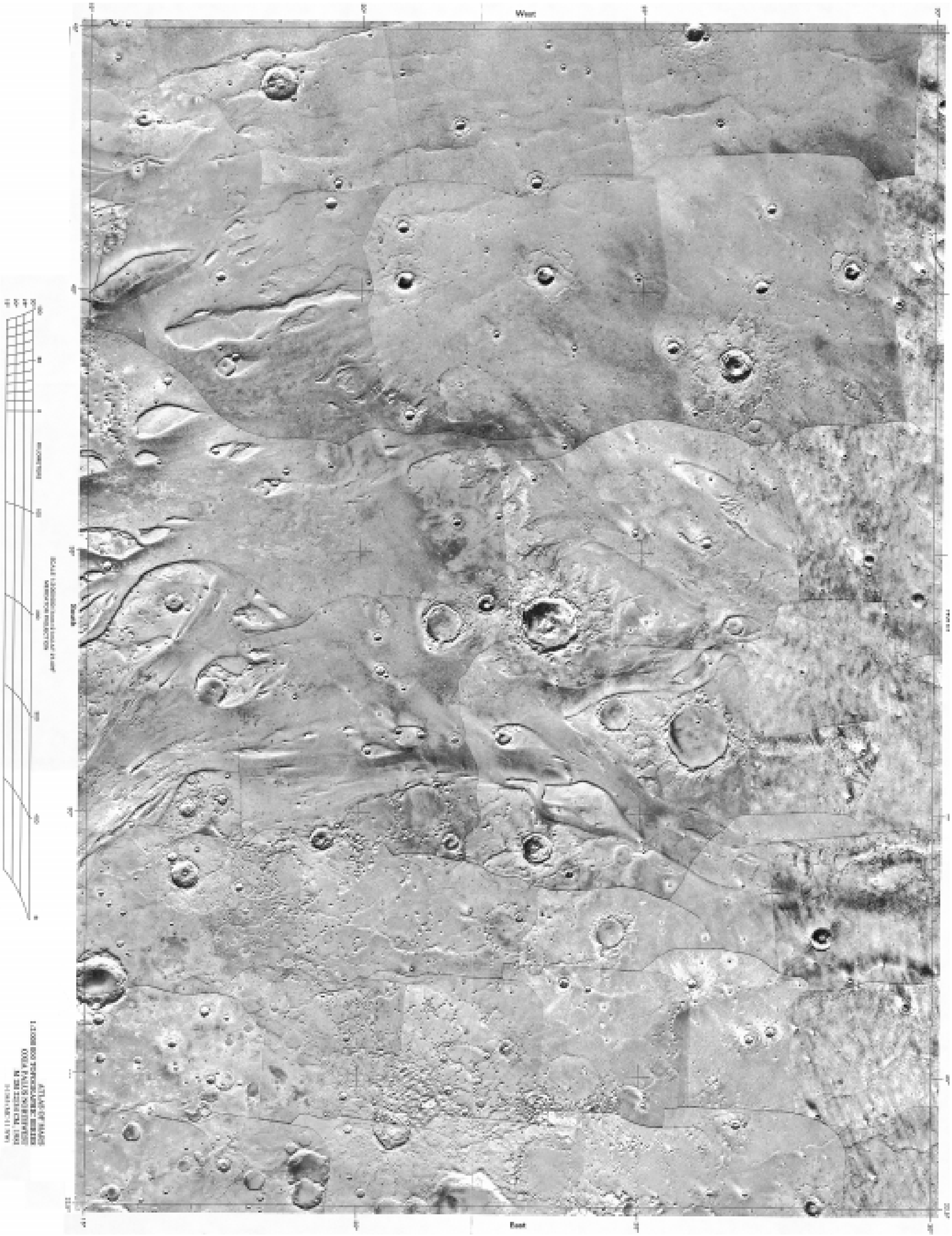


Image 4 Photomosaic of the terminus of Ares Vallis where it joins the Chryse Planitia. This photomosaic adjoins Image 7.

Image 5 Photomosaic showing where the Ares, Tiu, Simud and Shalbatana Valles join the Chryse Planitia. The inset shows the Scablands at the same scale. The scale is on the *south* edge if the image.

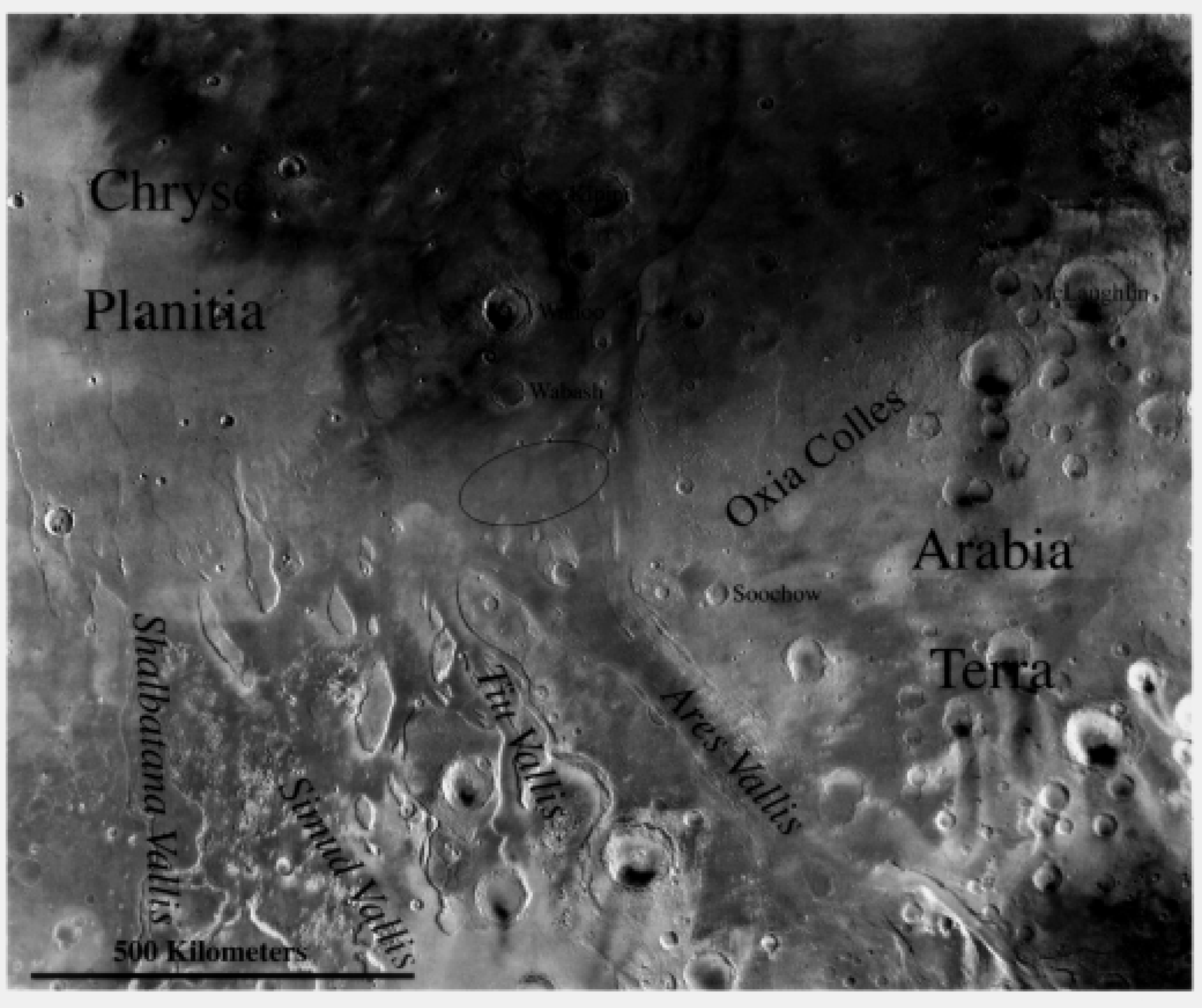


Image 6 Photomosaic showing the region surrounding the 100km x 200 km ellipse (superimposed on the image) that marks where NASA intends to land *Pathfinder*. From which directions might the spacecraft approach the landing?

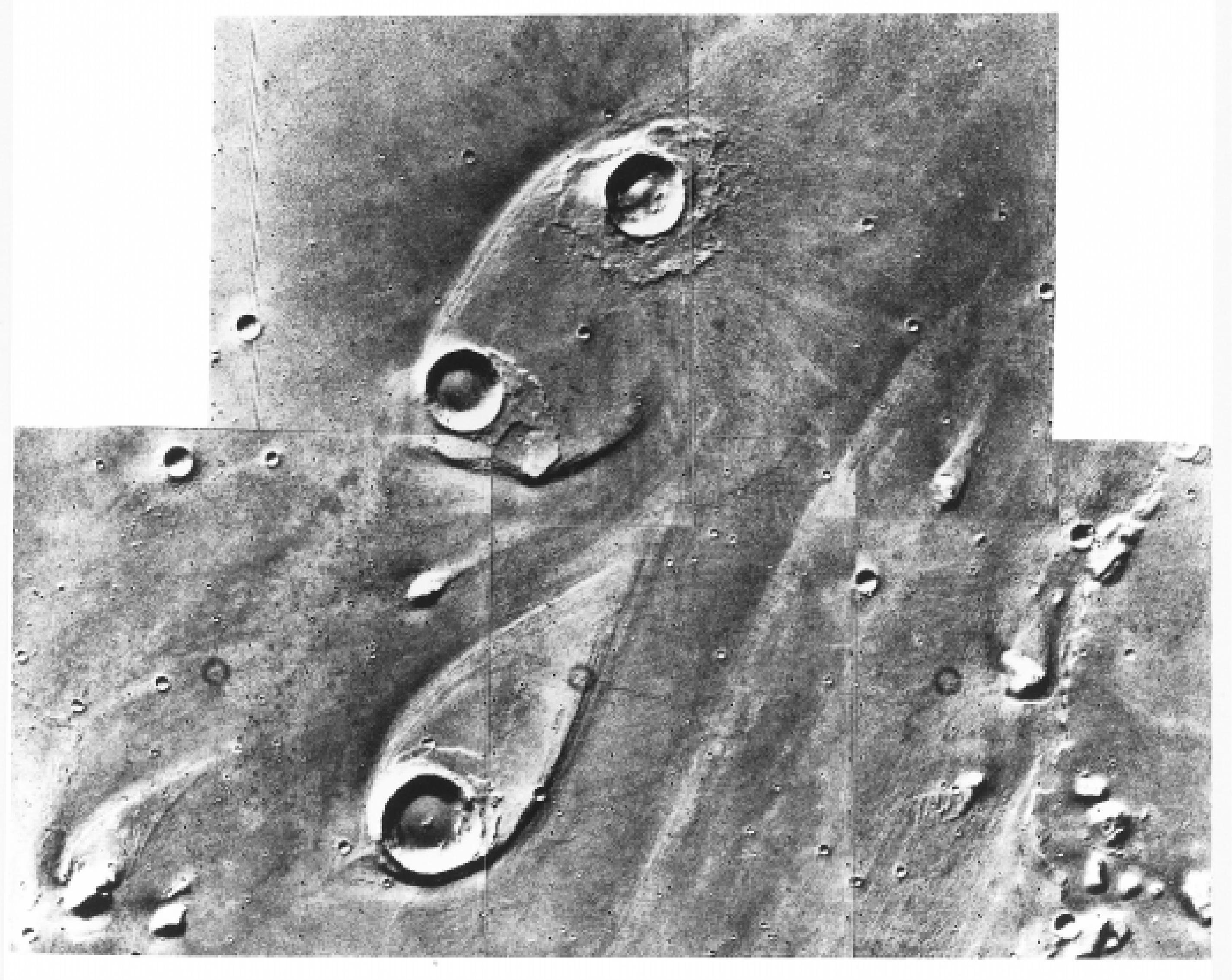


Image 10 Detail of the landforms at the mouth of the Ares Vallis. The landforms are about 45 km (28 mi) long. The southern landform is about 600 m (1,950 ft) tall and the northern landform is about 400 m (1,300 ft) tall. The largest crater is 10 km (6.25 mi) across. North is toward the top-right corner. (NASA image # 211-4987)